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The Adaptive Forms and Vortex-Motion of the Substance of the Red Blood-corpuscles of Vertebrates.

By John A. Ryder.

The fact that the red blood-corpuscles of vertebrates are discoidal or elliptical flattened bodies seems to have had very little of import to physiological writers. I shall now attempt to show that not only has the shape of these bodies very great physiological significance, but that these shapes are also adaptive. The attempt will also be made to show that it may be that there is a vortical flux of substance from the centre to the periphery, or from the periphery to the centre of every such corpuscle during life on both sides of it; that, moreover, such a flux taken in conjunction with the viscosity of the substance of the corpuscle and its original or embryonic globular form is responsible for its shape. The flattening and vortical flux of the substance of the corpuscle may be regarded as adaptive physiological devices by means of which its respiratory efficiency is vastly increased. That such a flux has never been seen and may never be seen, owing to the practical impossibility of observing these bodies in a perfectly normal living condition, is no proof that such a flux does not occur. Other practical difficulties also present themselves in the demonstration of the vortical flux of the substance of red blood-corpuscles, namely their optical homogeneity, as a result of which also the very highest powers of the microscope become useless in this investigation, since the particles of the substance lie beyond the limits of microscopic vision and cannot therefore be differentiated microscopically so as to demonstrate such a motion, even were it possible to observe the corpuscle in an active living state under perfectly normal conditions.

The first condition satisfied by the flattened form of the red blood-corpuscle is an increase of its superficial area. This would also be achieved if the corpuscle were elongated into a filament. But it can be shown that if these corpuscles were filaments they would inevitably tend to choke up or occlude the vessels, because of becoming tangled amongst one another and thus bringing the circulation to a stand-still with consequent death. It can also be shown, with all the rigor of mathematical demonstration, that the superficial area of a filament of the same volume as a disk of the same substance does not increase at anything like the same rate, if the filament is indefinitely and progressively lengthened, as compared with the rate of increase of the surface of a disk of similar volume indefinitely and progressively flattened. Everything is therefore in favor physiologically of the discoidal form of a mass of plasma as a hæmoglobin bearer over and above that of a filament or any other shape whatever. The advantages which accrue to the discoidal form of the blood-corpuscle over a hypothetical filamentous form are thus seen to be conditioned by the geometrical laws which hold in respect to the progressive and equal change of the ratios of two of the dimensions of a solid or fluid body as compared with an unequal change in its third dimension, provided there is no change of volume.

This form of the blood-corpuscle by means of which its area is increased is also one which involves the conception that the average path traversed by all of its constituent particles is less than that by means of which it would be transformed into a filamentous body. A further conclusion derivable from this fact is that in the transformation of the globular embryonic blood-cell there is less expenditure of energy involved in transforming it into a disk than if it were transformed into a filament. There is therefore an actual saving of energy consequent upon transforming the primitively globular blood-cells into disks instead of into filaments. Viewed, therefore, as a kinetic problem alone, it can be proved that the discoidal shape of the blood-corpuscles of vertebrates requires the expenditure of a relatively small amount of energy as compared with that of any other form that might be assumed.

Notwithstanding this fact, however, there has been an extension of the disks of many forms in one of their dimensions, so that in the greater proportion of vertebrates, including birds, reptiles, batrachia and fishes, the red corpuscles are elliptical, while in a mollusc *Arca* they are flattened and pyriform in outline. Nowhere, however, does the eccentricity of the elliptical form of the corpuscles develop great proportions; in fact, I know of no instances in which the great diameter of an elliptical corpuscle is as great as twice its least diameter. The law enunciated in the preceding paragraphs therefore still holds essentially even in those cases where the corpuscle becomes quite markedly elliptical, since nowhere does this ellipticity reach such an extreme as to become the expression of an extension of the substance of the corpuscle into the form of a filamentous body.

This ellipticity of the blood-corpuscles of the lower vertebrates is, moreover, again adaptive, since it is well known that in traversing the smallest capillaries in such forms as the frog, for example, every corpuscle must in traversing the latter place its long axis parallel, or nearly so, with the axis of the lumen of the vessel in order to pass through; in other words, the least diameter of the corpuscle only can traverse the lumen of capillaries. In thus adjusting its long axis to the axis of the lumen of the capillary, such a corpuscle again presents a maximum amount of surface and volume in the nearest relation to the tissues it is to oxidize, whereas if it traversed the capillary with its long diameter transverse to the axis of the lumen of the capillary, it would present the least amount of its volume and surface in the nearest relation to the tissue to be oxidized. Were this last condition prevalent it would require many more corpuscles to do the same work as is done by the elliptical corpuscles that now traverse the capillaries lengthwise, or with their long axes parallel with the axis of the lumina of the latter.

A further supposition that may be made regarding the elliptical blood-corpuscles is that, originally globular, they became at first discoidal, then elliptical, and that the elliptical form of the disks was consequent upon slight constraint within the capillaries during their passage through the latter; in other words, the elliptical form was derived from the discoidal as the discoidal was derived from the still more primitive globular form. We may also suppose that very slight mechanical constraint in passing through the capillaries would distinctly tend to develop a tendency towards converting the disks that were slightly too large to pass through the capillaries into elliptical disks. I can thus conceive a mechanical origin for the elliptical form of the red blood-corpuscle in general wherever it occurs.

It may also be assumed that the size of the corpuscle is directly related to the rate of metabolism of the organism. Thus in the sluggish batrachia the corpuscles are large; in the more active fishes and reptiles smaller; in mammals still smaller, and in the most active mammals and birds, such as the musk deer and humming bird, smallest of all, reaching minimum dimensions of $\frac{1}{4000}$ to $\frac{1}{6000}$ of an inch in these types, according to Gulliver.

The impulse that tends to develop a vortical flux of matter from opposite poles of a young globular red blood-corpuscle in every direction from the centre, it would be difficult to specify further than that it is purely physiological and adaptive, and leads to a distinct gain of surface and a consequent increase in the efficiency of each and every corpuscle in performing its function, that for such a cause has assumed the discoidal form. That such a double vortical flux must take place from two opposite poles of a primitively globular or embryonic red blood-corpuscle in passing from its primitive globular to that of its completed or adult elliptical or discoidal form is self-evident upon mere contemplation of the geometrical conditions that must on *à priori* grounds accompany the transformation of a semifluid globular mass to the form of a disk with rounded edges. If such a vortical flux of its substance were maintained by every corpuscle during its double cycle of wanderings through the systemic and pulmonary circulations and throughout life, its efficiency in the processes of metabolism must necessarily be greatly increased. The fact that Amœba cannot move without developing a vortical flux of its own substance through itself, is, it seems to me, evidence of the possibility and probability of the same thing occurring in red blood-corpuscles. If the foregoing hypothesis is true with respect to red blood-corpuscles, we have no less than ten millions of vortex rings of particles whirling together in pairs for every cubic millimeter of blood that circulates through the vessels of our bodies.

A Study of the Transformations and Anatomy of Lagoa crispata, a Bombycine Moth.

By Alpheus S. Packard.

The larva of this moth is exceptional among caterpillars, for it has the rudiments of two pairs of abdominal legs more than the five pairs common to all other known Lepidoptera. It is also remarkable for its metameric glandular abdominal processes.

A very full and careful account of the life-history of this interesting moth has been published by Dr. J. A. Lintner, in his *Entomological Contributions*, No. ii, p. 139. He describes six stages, and gives an interesting account of the cocoon and mode of pupation.*

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* See also two brief articles by myself: "On the Larva of Lagoa, a Bombycine Caterpillar with Seven Pairs of Abdominal Legs; with Notes on its Metameric Glandular Abdominal Processes." *Zoologischer Anzeiger*, 27. Juni, 1892, pp. 229-234; "The Bombycine Genus Lagoa, Type of a New Family," *Psyche*, July, 1892, pp. 281, 282.